NEUTRONIC ANALYSIS OF IFMIF-DONES TEST CELL COOLING SYSTEM

Gediminas Stankunas, Andrius Tidikas
Lithuanian Energy Institute, Laboratory of Nuclear Installation Safety
Kaunas, Lithuania
gediminas.stankunas@lei.lt

Ulrich Fischer
Karlsruhe Institute of Technology, Institute for Neutron Physics and Reactor Technology
Eggenstein-Leopoldshafen, Germany

Abstract

IFMIF-DONES (International Fusion Materials Irradiation Facility – DEMO-Oriented Neutron Source) is an accelerator based d-Li neutron source which aims at the qualification of materials at the irradiation conditions of a DEMO fusion power reactor as being developed in the frame of EUROfusion's Power Plant Physics and Technology (PPPT) programme. The high intense neutron radiation produced in the liquid lithium target results in a strong activation of the Test Cell (TC) with the High Flux Test Module (HFTM), housing the irradiation specimens, the TC steel liner and the water cooled concrete walls. The activation and decay heat generation of the TC facility needs to be assessed for maintenance, decommissioning and waste management purposes and the related safety analyses.

1. INTRODUCTION

Qualification of materials for future nuclear fusion technologies requires testing facility that could provide relatively large volume and intensity neutron irradiation with a capacity to produce significant damage and activation in sample materials. Furthermore such process should be accelerated in comparison to actual fusion reactor environment. IFMIF-DONES is irradiation facility designed to cope with such task. The basis of IFIMIF-DONES is superconducting radio frequency linear accelerator guiding 40 MeV deuterons to the lithium target. Deuteron interaction with lithium results in high energy neutron production that subsequently irradiates the sample materials [1].

Due to the magnitude of the neutron source all containment building will be exposed to the neutron irradiation, so prior the facility construction in-depth safety analysis must be performed. The Test Cell containing irradiation samples will be particularly susceptible to activation processes as it will have to endure a high neutron fluxes. The maintenance and handling of the samples will be conducted remotely inside the Test Cell, however estimation of the biological shielding irradiation effect must be provided in order to ensure safe operation and maintenance [2].

The main focus of this study is activation analysis of the cooling pipe system placed inside the biological shielding.

2. METHODS

Test Cell is surrounded by biological shielding composed of heavy concrete and stainless steel inner liner. Inner layer is an independent closed framework which is covered with liner from inside with a thickness of 8 mm. between the liner and inner shielding a set of water cooling pipes (Fig. 2-3) is placed. The cooling pipes in this setup are responsible for excess heat removal during the irradiation operation as neutrons will deposit significant amount of heat inside the shielding. On top of that, activated materials will also produce heat via decay processes.

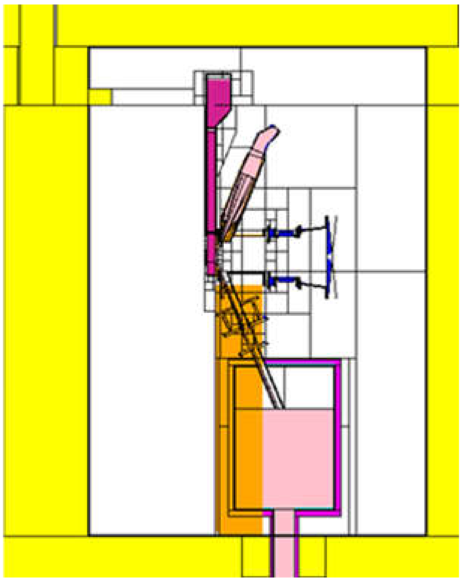

FIG. 1. Test Cell MCNP model used for calculations. Biological shielding are is colored in yellow.

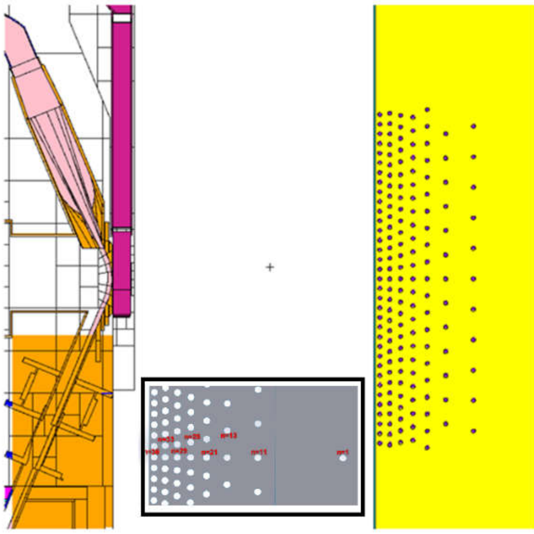

FIG. 2. Pipe placement inside the biological shielding.

Activation analysis was performed by coupling MCNP and FISPACT calculations. At first neutron transport calculations were performed with MCNP5+McDeliciuous [3] using JEFF-3.1.2 nuclear data library [4]. Test Cell model called “mdl82” (Fig. 1) was used together with neutron source specified by DONES project. Neutron fluxes were obtained for pipe localizations (Fig. 2). The statistical error of Monte Carlo calculation is close to 0.1% with 10^8 generated histories of particles.

Table. 1. Topology of the cooling pipe system

Layer #	1	2	3	4	5	6	7	8
number of pipes in layer	35	33	29	25	21	13	11	1
Pipe distance from wall surface (Xpipe, [mm])	26	83	145	215	297	403	561	1000
Height of enclosing rectangle (a, [mm])	56	60	67	78	98	140	176.5	0 - one pipe only

Investigated cooling setup consists of 168 pipes (Fig 3.) grouped into 8 layers. Each layer has a specific distance from the wall surface (table 1). The number of pipes in each layer lessens as the distance from the surface wall increases. The amount of water circulating in the biological shielding walls is expected to be about 0.88 m^3.

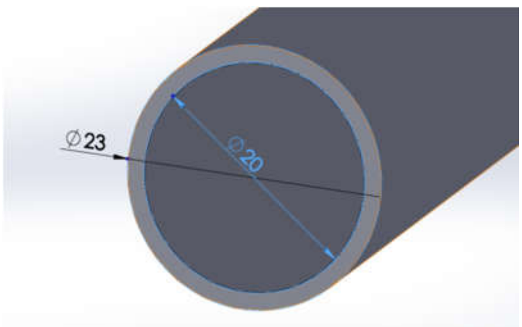

FIG. 3. Individual pipe dimensions

Obtained neutron fluxes were adjusted into neutron spectra with regards to operation of the facility and its total neutron yield. Typical neutron spectrum contains 211 neutron energy groups. The assumed operation runs for 30 calendar years (CY). Each year consists of 345 day full power irradiation and 20 days cooldown period corresponding to the maintenance time. Such irradiation scenario together with neutron spectra were used for the calculations of the activation characteristics.

Activation calculations were performed with FISPACT-II code [5] and TENDL-2015 nuclear data library [6]. Activity, dose rate and decay heat values were obtained for the subsequent cooling times: 0s, 1 s, 5 min, 30 min, 1 hr, 3 hr, 5 hr, 10 hr, 1 day, 3 days, 1 week, 2 weeks, 4 weeks, 8 weeks, 6 months, 1 year, 10 years, 50 years, 100 years, 300 years and 1000 years. Water circulation was excluded from this study as FISPACT code is only suitable for calculations in static environment.

3. RESULTS

The Activation characteristics were obtained and principal radionuclides were identified for the water cooling system. Total activity and decay heat values for different layers are shown in Figures 4 and 5.

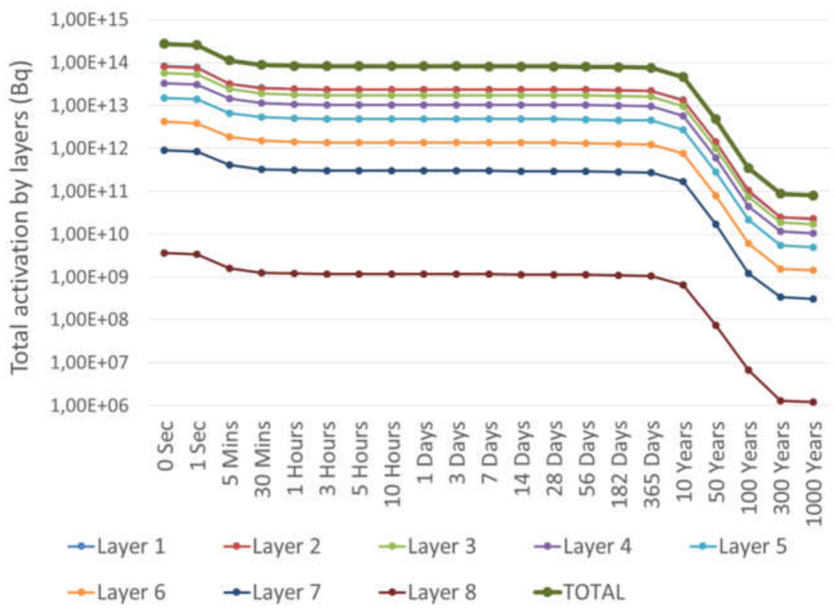

FIG. 4. Total activity of cooling pipes present in different layers

There are several key radionuclides with aggregate half-life ranging from 5 to 30 minutes. These nuclides are mostly the products of oxygen isotope reactions. In particular, N-16 (half-life 7.13 sec, 16O(n,p) reaction, β- decay resulting in high energy 6.13-MeV gamma emission) and O-15 (half-life 2.037 min, 16O(n,2n) reaction, β+ decay) constitute almost two orders more than the others in terms of decay heat and dose rate within first 5 minutes after end of irradiation. Furthermore they pose radiological risk during whole device operation period and shortly after its shutdown.

So for the safe operation, shutdown dose rates should be carefully estimated around the cooling system, more so system itself should be adequately shielded. Closed loops should also prevent activated coolant to leave radiation control zones.

Production of N-17 from $^{18}O(n,d)$ and $^{17}O(n,p)$ reactions is insignificant even though former reaction cross-section is larger than $^{16}O(n,p)$ as O-17 and O-18 isotopes account for less than in percent in natural abundance of oxygen isotopes. Figures from 6 to 8 present the time evolution of the principal radionuclides in terms activity, decay heats and contact dose rates in the water in the most inner layer after the stop of the irradiation.

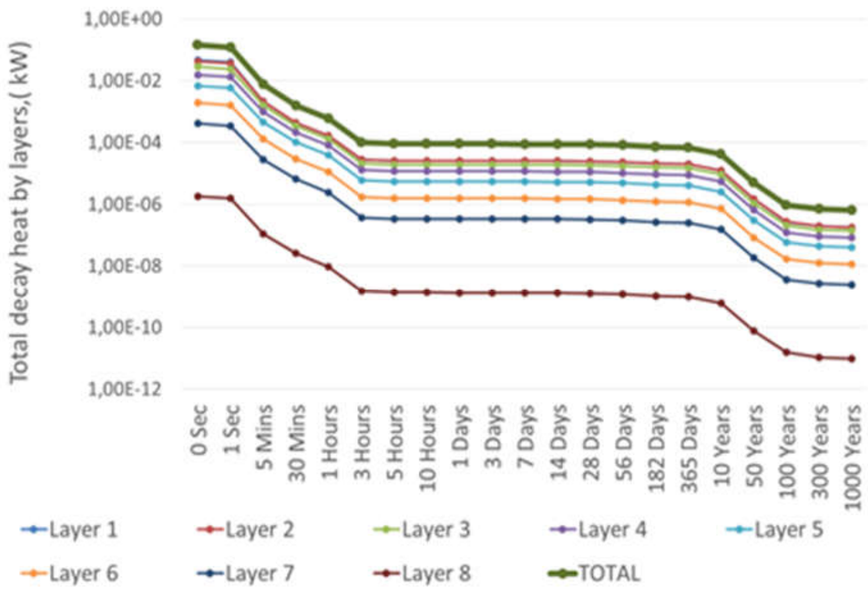

FIG. 5. Total decay heat of cooling pipes present in different layers

In general specific activities through the layers varies from ~$2 \cdot 10^{12}$ Bq/kg to ~$4 \cdot 10^{9}$ Bq/kg, while specific decay heats range from ~$1 \cdot 10^{-3}$ kW/kg to ~$2 \cdot 10^{-6}$ kW/kg just after the end of irradiation. Decay heats drop in value hundred times within 30 minutes of cooldown period and almost thousand times within 1 hour. Activity stays close to constant for almost a year due to tritium.

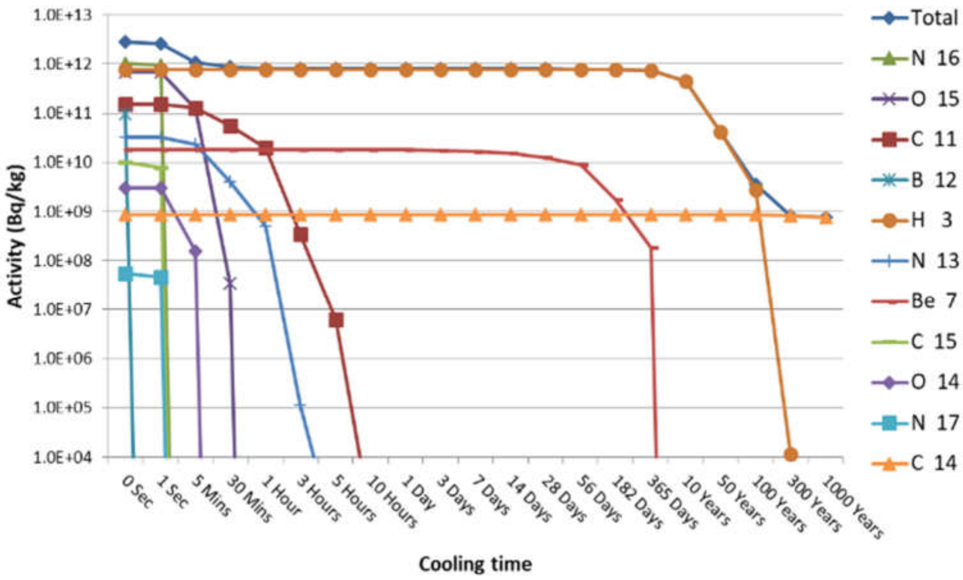

FIG 6. Time evolution of the principal radionuclides in terms of activity calculated for the TC cooling water in the most inner layer

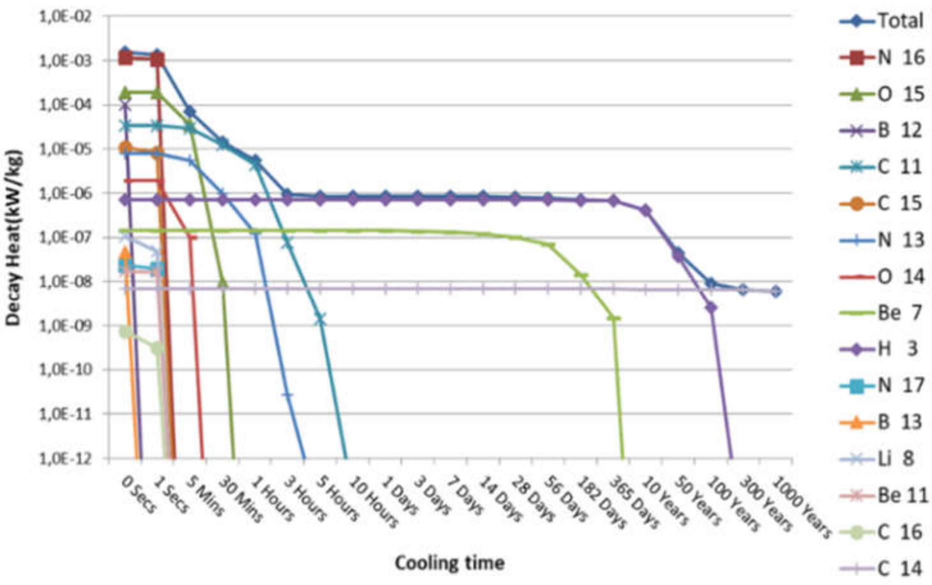

FIG 7. Time evolution of the principal radionuclides in terms of decay heat calculated for the TC cooling water in the most inner layer

The biggest radiological hazard in cooling systems with water as coolant is N-16 nuclide, which is heavy gamma emitter as well as a nuclide responsible for the highest activities, dose rates and decay heats for few seconds after the end of irradiation in most examined cases. Tritium has a tendency to accumulate as operation time increases in contrast to N-16, so it can overtake N-16 as the most active nuclide. More so tritium becomes marginally more active in comparison to N-16 as the pipe placement is set further from the source.

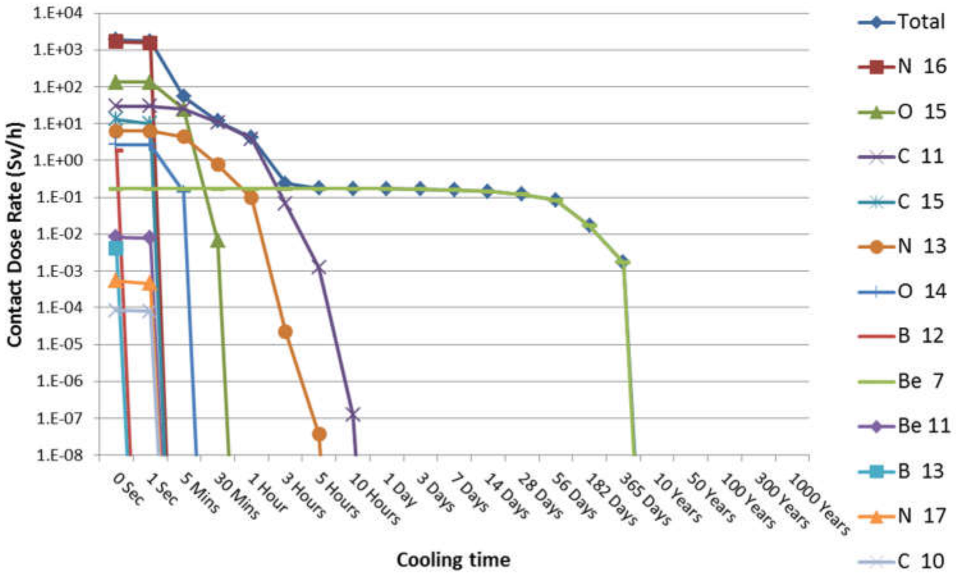

FIG 8. Time evolution of the principal radionuclides in terms of contact dose rate calculated for the TC cooling water in the most inner layer

4. SUMMARY

IFMIF-DONES is still in a development phase with multiple studies ongoing with regards to its radiological impact on the environment. This work was devoted for the coolant activation analysis, where set of pipes in Test Cell zone are affected by intense neutron radiation. Pipes are placed in different locations separated by certain distance.

It was determined that the specific average activity and decay heat after the end of irradiation in coolant near the wall surface was around $\sim 2 \cdot 10^{12}$ Bq/kg and $\sim 1 \cdot 10^{-3}$ kW/kg. Contact dose rate at same locations peaked to $\sim 1 \cdot 10^{3}$ Sv/h.

The biggest concern in the water cooling systems is N-16 nuclide which while having rather short life time is still serious radiological hazard throughout the operation of the device. Tritium is the only product in the coolant relevant in terms of activity for time periods greater than 1 day after the end of the irradiation, so it can be assumed that impurities and corrosion products in coolant will have higher impact than the pure coolant itself as time goes by.

ACKNOWLEDGEMENTS

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